THE DESIGN OF A REINFORCED CONCRETE CHIMNEY

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INDEBTEDNESS

The author wishes to express his indebtedness to professors, Gebhardt and Reinert for the generous aid given in the preparation of this thesis.

INTRODUCTION.

The proposed location of this chimney is in Chicago; Illinois and it is assumed that the plant will burn Illinois screenings.

The wind pressure was taken at 22# per square foot of projected area, being the value given in the specifications of the city of Chicago.

The top of the base was assumed to be at the surfase of the ground and the top of the chimney is supposed to be 202' above the damper in the boiler room.

All conditions were regarded as being ordinary favorable conditions. No attempt has been made to design for any extra-ordinary condition. Theearth is regarded as common dry clay which is to be excavated to a depth of 7'-0".No difficulty is anticipated in either the excavation or the removal of same.

In designing this chimney referance has been made to the chapters on chimneys as given in thr text books of Turneaure and Mauer, Principals of Reinforced Concrete, and to Gebhardt's, Steam Power Plant Engineering.

Determination of Height and Area of Chimney.

The chimney will be designed for water-tube boilers, rated at 1500 horse power, equipped with chain grates and burning Illinois coal; boilers rated at 10 square feet of heating surface per horsepower; ratio of heating surface to grate surface 50:1, flue 100' long with two right angle bends; stack to be able to carry 50% overload; temperature of flue gases at overload 540 degrees Fahrenheit; calorific value of coal 11,200B.T.U. per pounds.

Maximum boiler horsepower $1500 \times 1.5 = 2250$H.P.

Heat equivalent of one boiler horsepower hour $= 34.5 \times 970.4 =$ 33479 B.T.U.

Coal per boiler horsepower hour $= \frac{33479}{11,200 \times 70} = 4.3$#

Assume that the efficiency of the boilers is 70%

Total grate surface required $= \frac{1500 \times 10}{50} = 300$ sq. ft.

Coal burned per hour $= 4.3 \times 2250 = 9650$#

Maximum rate of combustion $= \frac{9650}{300} = 32.3$# per square feet of grate surface per hour.

Assume pressure losses at maximum rating. Losses through fuel and grate o.34 inches of water. L oss in boiler (furnace to stack side of damper) o.55

Loss in flue 100' at 0.1 in. per hundred = 0.10 .

Loss in turns 2 x 0.05 = 0.10.

Total oss or required effective pressure measured at flue entrance of stack = 1.09 inches of water.

$$\text{Theoretical draft} = \frac{1.09}{0.8} = 1.36 \text{ in.}$$

NOTATION

D = maximum theoretical static draft in. of water.

A = effective height of the chimney in feet.

d_a = density of outside air in pounds per cubic foot.

d_c = density of inside gas in pounds per cubic foot.

0.192 = factor for converting pressure in pounds per square feet to inches of water.

$$D = 0.192\, H(d_a - d_c) \quad (1)$$

Neglecting the influence of the relative humidity of the air

$d_a = 0.0807 \dfrac{P_a}{P} \times \dfrac{T}{T_a}$ in which P_a = observed atmospheric pressure in pounds per square inch. P = standard atmospheric pressure in pounds per square inch. T = absolute temperature at freezing point in degrees Fahrenheit. T_a = absolute temperature of the outside air in degrees Fahrenehit.

The density of chimney gases varies with the nature of the fuel and the air excess used in burning the fuel.

An average value is 0.085# per cubic feet at 32 degrees Fahrenheit, and pressure P.

$$\text{Therefore } D_c = 0.085 \frac{P_c}{P} \times \frac{T}{T_c}$$

T_c = absolute temperature of the chimney gases in degrees Fahrenheit. Substituting the value of d_a and d_c in equation (1) and assuming $P_a = P_c$

$$D = 0.192H \frac{P_a}{P} \left(\frac{0.0807\ T}{T_a} - \frac{0.085\ T}{T_c} \right) \quad (2)$$

Assuming $P_a = P = 14.7$ and $T = 492$ equation (2) reduces to;

$$D = 0.192\ H \frac{14.7}{14.7}, \left(\frac{0.0807 \times 492}{T_a} - \frac{0.085 \times 492}{T_c} \right)$$

$$D = H \left(\frac{7.64}{T_a} - \frac{7.95}{T_c} \right)$$

In the problem under consideration D is figured as 1.36 square inches. T_a taken at 60 degrees Fahrenheit equal 520. T_c taken at 540 degrees Fahrenheit = 1010

$$1.36 = H \left(\frac{7.64}{520} - \frac{7.95}{1010} \right)$$

$$1.36 = H \left(.0147 - .0072 \right)$$

$$H = \frac{1.36}{.00675} = 202 \text{ feet.}$$

Therefore the height of the chimney will be made 200 feet high.

We will consider that conditions are such that the top, of the chimney will be 202' above the damper in the

boiler room.

The area of the chimney will be found by Kent's empirical formula, since it is based upon the same conditions as found in the problem under consideration. Kent's equation is based on the consumption of 5# of coal per boiler horse power hour. Since we have assumed a consumption of 4.3#, then $\frac{4.3}{5} = 0.86$ the factor by which Kent's formula should be multiplied. Effective area $= .86 \left(\frac{3\ HP}{\sqrt{H}} \right) = .86 \left(\frac{3 \times 2250}{\sqrt{200}} \right) = 40.7$ square feet. $40.7 \times 144 = 5870$ square inches. $\pi r^2 = 5870$ $r^2 = 1870$ $r = 44$ inches. $D = 88"$. Therefore the inside area of the chimney at the top will be taken as 7'-10".

The opening of the flue to the chimney will be taken about 15% greater than the area of the chimney at the top. Flue opening will be made 12'-0" high by 5'-0" wide. Area equals 60 square feet.

GENERAL DESCRIPTION.

The chimney will be 200'-0" high. The inner diameter at the top will be 7'-10", and the outer diameter at the top will be 8'-8".

The thickness of the shell at the top will be 5". The thickness of the shell will increase uniformly at the rate of 1/32" per foot; the thickness of the shell at the base will, therefore, be 11¼".

The outer diameter will increase uniformly at the rate of 3/8" per foot. The outer diameter at the base will be 14'-11".

It is assumed that conditions are such, that by constructing a chimney 200 feet high, the top of the chimney will be 202 feet above the damper in the power house.

NOTATION

A = area of chimney section under consideration;

A_s = total area of all steel sections there;

W = weight of superincumbent portion of chimney;

P = wind pressure on that portion;

M = bending moment at the section;

e = distance from the center of the section to where the resultant of the weight and wind pressure cuts the section, "eccentric distance";

f_c = unit stress in concrete adjacent to the steel at lee side;

f_c' = unit stress in concrete adjacent to steel at windward side;

f = unit stress in concrete at the lee side;

f' = unit stress in concrete at the windward side;

f_s = unit stress in steel at the windward side;

m = a coefficient such that f mW/A;

m' = a coefficient such that f' $m'W/A$;

p = steel ratio, i.e., A_s/A;

n = ratio of modulus of elasticity of steel to that of concrete.

r = the distance from the center of the section under consideration, to the center of the concrete shell.

VERTICAL REINFORCEMENT

Determined at a section 75'-0" from the top of the chimney.

For this section, it is assumed that 22, ½" square rods are to be used.

The wind pressure will be taken as 22# per sq. ft. of projected area.

Determination of the weight of the concrete above this section.

The thickness of shell at this section is 75/32" + 5" = 7.34" The outer diameter is 8'-8" + 75" x 3/8" = 11' -.2" Since the chimney is in the shape of a frustum of a hollow cone, the volume of concrete will be determined by subtracting the volume of the frustum of the hollow cone from the volume of the frustum of the cone by the outside of the chimney. The formula: $V' = 1/3\ H\ (B+b+\sqrt{Bb})$, will be used in determining the volume. Where B is the area of the base, b the area of the top, h perpendicular height.

$$B = \pi r^2 = 3.1416 \times 5.5 = 95 \text{ sq. ft.}$$

$$b = \pi r^2 = 3.1416 \times 4.33 = 58.6 \text{ sq. ft.}$$

$$\frac{1}{3} h = \frac{75}{3} = 25$$

$$V' = 25 \left(95 + 58.6 + \sqrt{95 \times 58.6}\right) = 5700 \text{ cubic feet.}$$

To find the volume of the hollow

$$V = \frac{1}{3} h \left(B + b + \sqrt{Bb}\right)$$

The inner diameter at the top is 7' - 10". The inner diameter at the section is 11' - 14.68" = 9.775'

$$B = \pi r^2 = 3.1416 \times 4.89^2 = 75.0 \text{ sq. ft.}$$

$$b = \pi r^2 = 3.1416 \times 3.915^2 = 48.2 \text{ sq. ft.}$$

$$\frac{1}{3} h = 25'$$

$$V = 25\left(75 + 48.2 + \sqrt{75 \times 48.2}\right) = 4570 \text{ cubic feet}$$

The volume of concrete equals V' - V = 5700-4570 = 1130 cubic feet.

The weight above the section is 1130 x 150 = 170,000#

To find the bending moment.

The average projected area is 9.83 square feet.

Therefore, M=75 x 22 x 9.83 x 37.5 x 12 = 7,3000,000"#

Where 75 is the height of the section, 22 the pressure of the wind, 9.83 the average projected area and 37.5 the lever arm.

$$e = \frac{M}{W} = \frac{7{,}300{,}000''\#}{170{,}000} = 43''$$

$$2\,r = 11'\text{-}7.34''\ (.61') = 10.39'$$

$$r = 5.20' \text{ or } 62.4''$$

$$\frac{e}{r} = \frac{43}{62.4} = .69$$

$A_s = 5.5 (22, \frac{1}{2}"$ square rods)

$A = (95-75)\ 144 = 2880$ square inches.

$$p = \frac{A_s}{A} = \frac{5.5}{2880} = .00197$$

From the tables of Turneaure and Maurer, $m = 2.4$

$$f = m\frac{W}{A} = 2.4 \times \frac{170,000}{2880} = 142\#\text{ per square inch.}$$

This value is O.K., therefore, the amount of reinforcement assumed will be used. i.e. $22, \frac{1}{2}"$ square rods.

An investigation will now be made to determine the amount of reinforcement required at a section 125'-0" from the top.

The outer diameter at this section is 12.57'. The thickness of the shell is 8.9".

To find the weight above this section.

$$V' = \frac{1}{3} h (B + b + \sqrt{Bb})$$

B. is the area of the base, b the area of the top, h the perpendicular height.

$$B = \pi r^2 = 3.1416 \times 6.28^2 = 124 \text{ square feet}$$

$$b = \pi r^2 = 3.1416 \times 4.33^2 = 58.6 \text{ square feet}$$

$$\frac{1}{3} h = \frac{125}{3} = 41.66'$$

$$V' = 41.66 (124 + 58.6 + \sqrt{124 \times 58.6}) =$$

11150 cubic feet.

For hollow section

$$V = \frac{1}{3} h (B + b + \sqrt{Bb})$$

The diameter of hollow at top 7.83'. Diameter of hollow at section 11.09'

$$B = \pi r^2 = 3.1416 \times 5.545^2 = 96.5 \text{ sqare feet}$$

$$b = \pi r^2 = 3.1416 \times 3.915^2 = 48.2 \quad " \quad "$$

$$V = 41.66 (96.5 + 48.2 + \sqrt{96.5 \times 48.2}) = 8760 \text{ cubic feet.}$$

Volume $= V' - V = 11150 - 8760 = 2390$ cubic feet.

$W = 2390 \times 150 = 359,000\#$

To finding the bending moment.

The diameter of themaverage section from the top, to the section 125' from the top is 10.63'.

Therefore, $M = 10.63 \times 125 \times 22 \times 62.5 = 1,830,000'\#$

$$1,830,000 \times 12 = 21,950,000''\#$$

$$e = \frac{M}{W} = \frac{21,950,000''\#}{359,000\#} = 61.2''$$

Since the resultant force falls far outside of the kern of the section, I will proceed according to case II, Turneaure and Maurer page 418.

$$r = (6.28 - .371)12 = 70.91''$$

where 6.28 is outer radius, .371 is half the thickness of the shell in feet.

$$\frac{e}{r} = \frac{61.2}{70.91} = .863$$

$$A = (124 - 96.5)\ 144 = 3960 \text{ square feet.}$$

$$\frac{W}{A} = \frac{359,000}{3960} = 90.5\# \text{ per square inch.}$$

With f_c and f_s limited to 500# per square inch, and 15,000# per square inch respectively, hence if the amount of steel is just sufficient to make $f_c = 300\#$ per square inch, then $m = \frac{300}{90.5} = 3.32$

The from the diagram figure 5 with $m = 3.32$ and $\frac{e}{r} = .863$; p will equal .002, $f_s/f_c = 18$

$f_s = 18 \times 300 = 5400\#$

These values are low but O.K. $A_s = Ap = 3960 \times .002 = 7.92$

Use 22, 5/8" square rods. $A_s = 8.54$.

An investigation of the amount of reinforcement necessary at a distance of 175' from the top.

The outer diameter will be $8'8'' + 175 \times \frac{3''}{8} = 170'' = 14.16'$.

The thickness of shell will be $5'' + \frac{175''}{32} = 10.47''$.

At this section the flue opening will be found, which is 5'-0" wide.

To find the weight of concrete above this section, (in determining the weight, the opening will not be considered).

$$V' = \frac{1}{3} h \left(B + b + \sqrt{Bb}\right)$$

$$B = \pi r^2 = 3.1416 \times 7.08^2 = 157 \text{ square feet}$$

$$b = \pi r^2 = 3.1416 \times 4.33^2 = 58.6 \text{ square feet}$$

$$\frac{1}{3} h = \frac{175}{3} = 58.33'$$

$$V' = 58.33 \left(157 + 58.6 + \sqrt{157 \times 58.6}\right)$$

$$V' = 58.33 \left(157 + 58.6 + 96\right) = 18,100 \text{ cubic feet}$$

For the hollow.

$$V = \frac{1}{3} h \left(B + b + \sqrt{Bb}\right)$$

$$B = \pi r^2 = 3.1416 \times 6.21^2 = 121.2 \text{ square feet}$$

$$b = \pi r^2 = 3.1416 \times 3.915^2 = 48.2 \text{ square feet}$$

$$V = 58.33 \left(121.2 + 48.2 + \sqrt{121.2 \times 48.2}\right)$$

$$V = 58.33 \left(121.2 + 48.2 + 76.5\right) = 14320 \text{ cubic feet}$$

Volume $= V'-V = 18100-14320 = 3780$ Cubic feet.

$$W = 3780 \times 150 = 566,000\#$$

The outer diameter of the average section above the section 175' from top is 11.38'

$M = 175 \times 22 \times 11.38 \times 87.5 \times 12 = 46,100,000''\#$

Where 22 is the wind pressure, and $87\frac{1}{2}$ lever arm.

$$e = \frac{M}{W} = \frac{46,100,000}{566,000} = 81.4''$$

$$r = \frac{14.16 \times 12}{2} - \frac{10.47}{2} = 79.72$$

$$\frac{e}{r} = \frac{81.4}{79.72} = 1.03$$

Since the flue opening occurs at this section A =

$(157 - 121.2)\,144 - 10.47 \times 60 = 5155.2 - 628.2 = 4527$ sq.in.

(The amount of material taken out for the flue will be approximately 1047 x 60 or 628.2 square inches.

$$\frac{W}{A} = \frac{566,000}{4527} = 125 \text{ lb. per square inch.}$$

If the amount of steel is just sufficient to make $f_c = 500$

$$m = \frac{500}{125} = 4.0$$

Therefore with $m = 4.0$, $\frac{e}{r} = 1.03$, $p = .0025$ $f_s/f_c = 27.0$

$$f_s = 27 \times 500 = 13500$$

$$A_s = Ap = .0025 \times 4527 = 11.4$$

These values are O.K. Use 30, 5/8" square rods $A_s = 11.7$

For the section just above the flue opening the values are taken the same as at the section 175 ft. from the top, with the exception that A will be greater. An investigation will be made to determine the stresses in the sections just above the flue opening.

$$A = 5155.2; \quad \frac{W}{A} = \frac{566,000}{5155.2} = 110$$

$\frac{e}{r} = 1.03$, with $p = .0025$, $m = 4.0$ $f_s / f_c = 27.0$

$$f_c = 4 \times 110 = 440$$

$$f_s = 440 \times 27 = 11,190$$

Since these values are fairly high the same amount of steel will be used as at the section 175 feet from the top.

To investigate the amount of reinforcement necessary at the base.

The outer diameter at the base is 14 feet 11 inches, or 14.92'.

The thickness of shell at the bottom is 11.25".

To find the volume of concrete.

$V' = \frac{1}{3} h \left(B + b + \sqrt{Bb}\right) \qquad B = \pi r^2 \quad 7.46^2 \times 3.1416 =$ 175.0 square feet.

$b = \pi r^2 = 3.1416 \times 4.33^2 = 58.6$ square feet.

$$\frac{1}{3} h = \frac{200}{3} = 66.66'$$

$$V' = 66.66 \left(175 + 58.6 + \sqrt{175 \times 58.6} \right)$$

$V' = 66.66 \left(175 + 58.6 + 102.5 \right) = 22{,}400$ cubic feet.

To find the volume of hollow.

$$V \quad \frac{1}{3} h \left(B + b + \sqrt{Bb}\right)$$

The diameter of hollow at bottom = 13.07, the diameter of hollow at the top = 7.83.

$$B = \pi r^2 = 3.1416 \times 6.54^2 = 134.2$$

$$b = \pi r^2 = 3.1416 \times 3.915^2 = 48.2$$

$$V = 66.66 \left(134.2 + 48.2 + \sqrt{48.2 \times 134.2}\right)$$

$V = 66.66 \left(134.2 + 48.2 + 80.4 = 17{,}510\right.$ cubic feet.

Volume $V' - V = 22{,}400 - 17{,}510 = 4890$ cubic feet.

$W = 4890 \times 150 = 734{,}000\#$

To find bending moment.

Diameter at average section $= 11.79'$

$M = 200 \times 11.79 \times 22 \times 100 = 5,190,000$ foot pounds.

$$5,190,000 \times 12 = 62,250,000''\#$$

$$e = \frac{M}{W} = \frac{62,250,000}{734,000} = 84.7''$$

$$r = \frac{14.92}{2} - \frac{11.25}{2 \times 12} = 6.98 \times 12 = 84.0$$

$$\frac{e}{r} = \frac{84.7}{84} = 1.009$$

$A = (175 - 134.2)\ 144 = 5872.2$ square inches.

$$\frac{W}{A} = \frac{734,000}{5875.2} = 125\#\text{ per square inch.}$$

If the amount of steel is necessary to make f_c 500, then

$$m = \frac{500}{125} = 4.0$$

Then from the diagram #5, $p = .0025 \quad f_s / f_c = 27.$

With this percentage of steel, $f_s = 27 \times 500 = 13500$ which is O.K.

$$A_s = Ap = .0025 \times 5875.2 = 14.7$$

Using 3/4 inch square rods, the number required is 27.

NOTATION

t = thickness of concrete shell at the section under consideration;

r_1 = inner radius of shell;

r_2 = outer radius of shell;

T = difference of temperatures of concrete at outer and inner faces;

K = coefficient of expansion of concrete and steel;

E_c = modulus of elasticity of concrete in compression;

E_s = modulus for steel;

f_c = temperature unit stress in concrete (circumferential) at inner face; and

f_s = temperature unit stress in circumferential steel.

HORIZONTAL REINFORCEMENT

The following formulas give the values of the unit compression in the concrete and unit tension in the steel, at any place in the chimney:--

$f_c = T\ K\ E_c\ m_c$ $\qquad\qquad$ $f_s = T\ K\ E_s\ m_s$

The values m_c & m_s are multipliers which depend on the percentage of hoop reinforcement, etc. These values were taken from the curves of Turneaue and Maurer, principles of Reinforced Concrete page 426.

Gases in a chimney have a temperature of about 540 degrees Fahrenheit. However, as the gases ascend in the chimney they are cooled. The lower part of the chimney is protected from the excessive temperature of the gases, by the use of radial brick lining. It is, therefore, considered that the difference in temperature between the inner and outer shell of the chimney will not be greater than 200 degrees Fahrenheit.

Investigation of the amount of horizontal reinforcement necessary at the smoke hole section. The outer diameter at this section is 14.16'. The inner diameter is 12.42'

The center of the steel is placed 3" from the outer surface of the shell. The ratio of the outer radius to the inner radius $\frac{r_2}{r_1} = \frac{7.08}{6.21} = 1.14.$

The percentage of steel is $\frac{.1964}{9 \times 10.25} = .0022$ or .22%

The hoops are ½" round rods and they are spaced 9" c - c.

$$K' = \frac{3}{10.25} = .293$$

Then from the table, $m_c = 0.17$ $m_s = 0.45$

$$f_c = T \ K \ E_c \ m_c$$

$K = .000006$ $E_c = 2,000,000$ $T = 200$ $f_c = T \ K \ E_c \ m_c$

$$f_c = 200 \times .000006 \times 2,000,000 \times 0.17$$

$f_c = 407$, which is O.K.

$$f_s = T \ K \ E_s \ m_s$$

$E_s = 30,000,000$ pounds per square inch.

$$f_s = 200 \times .000006 \times 30,000,000 \times .45$$

$f_s = 16200$, which is O.K.

Reinforcement at section 125 feet from the top. The thickness of the shell is 8.9". The outer diameter is 12.57 feet. The inner diameter is 11.09'.

$$\frac{r_2}{r_1} = \frac{6.285}{5.545} = 1.13$$

½" round hoops will be used, spaced 9" center to center.

The percentage of steel is $\frac{.1964}{9 \times 8.9} = .00246 = .246\%$

The rods will be placed 3" from the edge of the concrete.

$$k' = \frac{3}{8.9} = .337$$

Then from the diagram, $m_c = .16$ $m_s = .41$

$$f_c = T\ K\ E_c\ m_c$$

$$f_c = 200 \times .000006 \times 2{,}000{,}000 \times .16 \qquad f_c = 384^{\#}$$

$$f_s = T\ K\ E_s\ m_s$$

$$f_s = 200 \times .000006 \times 30{,}000{,}000 \times .41 \qquad f_s = 14700$$

These values are O.K.

Investigation of the reinforcement necessary at section 75 feet from the top.

The thickness of shell is 7.34". The outer diameter is 11 feet. The inner diameter is 9.775 feet.

$$\frac{r_2}{r_1} = \frac{5.55}{4.89} = 1.13$$

½" round hoops will be used, spaced 9" center to center.

The percentage of steel is $\frac{.1964}{7.34 \times 9} = .00298 = .298\%$

The rods will be placed 2½ inches from the edge of the concrete.

$$k' = \frac{2.5}{7.34} = .34$$

Then from the diagram, $m_c = .18$ $m_s = .40$

$$f_c = T\ K\ E_c\ m_c$$

$$f_c = 200 \times .000006 \times 2{,}000{,}000 \times .18$$

Therefore $f_c = 433\#$ per sq. in.

$f_s = T\ K\ E_s\ m_s$

$f_s = 200 \times .000006 \times 30{,}000{,}000 \times .40 = 14{,}400\#$

Therefore these values are O.K.

Investigation of the reinforcement at the top.

The thickness of the shell is 5". The outer diameter is 8.66'. The inner diameter is 7.83'.

$$\frac{r_2}{r_1} = \frac{4.33}{3.91} = 1.11$$

½" round rods will be used, spaced 9" center to center.

The percentage of steel is $\frac{.1964}{9 \times 5.00} = .00436$

The hoops will be placed 2" from the edge of the concrete.

$$k' = \frac{2}{5} = .4$$

From diagram $m_c = .20$ $m_s = .35$ $f_c = T\ K\ E_c\ m_c$

$f_c = 200 \times .000006 \times 2{,}000{,}000 \times .20$ $f_c = 480\#$

$f_s = T\ K\ E_s\ m_s$

$f_s = 200 \times .000006 \times 30{,}000{,}000 \times .35$ $f_s = 12600\#$

DESIGN OF FOUNDATION.

NOTATION

W = total weight of chimney and earth filling over the baee;

M = wind moment at the bottom of the base;

A = area of the bottom of the base;

p_1 = maximum unit pressure on bottom;

p_2 = minimum unit pressure on bottom;

r = kern radius of bottom in direction of wind;

e = eccentricity at bottom of resultant of the wind pressure and W, $e = M/W$.

Assume base to be a square and the top of the base to be at the surface of the ground, so that the only earth filling will be that which is necessary to cover the foundation from view.

The wind moment at the bottom of the base is;

$M = 207 \times 11.79 \times 22 \times 103.5 \times 12 = 66,700,000''\#$

Where 207 is the distance to the top of the chimney frommthe bottom of the base, 11.79 the average section diameter, 22 the pressure of the wind and 103.5 the lever arm.

The weight of the base will be estimated at 900,000# total weight of the structure will be approximately

$734,000 + 900,000 = 1,634,000.^{\#}$

$$e = \frac{M}{W} = \frac{66,700,000}{1,634,000} = 40.7'' \text{ or } 3.4'$$

The base will be made a square 34' x 34'. The diagonal distance is 48.2'. The kern diameter is 1/6 diagonal distance =

$\frac{48.2}{6} = 8.03.$

The kern radius therefore is 4.02'.

The maximum pressure on the base is given by the formula; $p' = \frac{W}{A} + \frac{M}{Ar}$ $\qquad A = 34 \times 34 = 1156$ square feet.

$$r = 4.02 \text{ feet}$$

$$p' = \frac{1{,}634{,}000}{1156} + \frac{66{,}700{,}000}{1156 \times 4.02}$$

$$p' = 1415 + 1435 = 2850\#$$

Ordinary soil will hold this pressure.

$$p_2 = \frac{W}{A} - \frac{M}{Ar} = 1415 - 1435 = 20\#$$

Since these values are not excessive the base will be constructed according to the original assumption.

The shape of the base will be in the form of a trapezoid, with the lower base 34 feet by 34 feet by 3 feet. The upper side of the base will be 16 feet by 16 feet and will be 4 feet above the square part of the base.

COMPUTATION OF WEIGHT.

Volume of rectangle equals, 34 x 34 x 3 = 3460 cubic feet.

Volume frustom of pyramid = $V = \frac{1}{3} h \left(B + b + \sqrt{Bb} \right)$

$B = 34 \times 34 = 1156$ $b = 16 \times 16 = 256$ square feet.

$$V = \frac{4}{3} \left(1156 + 256 + \sqrt{1156 \times 256} \right) = 2600.$$

Total volume = 3460 + 2600 = 6010 cubic feet.

Weight = 6010 x 150 = 915,000 pounds.

The bricks weigh about 50,000 pounds. The estimated weight was 900,000. The actual weight is 965,000 pounds. This is considered close enough.

Determination of the reinforcement necessary in the foundation.

Part of the base acts as a cantilever. The pressure per square foot on the cantilever will be considered 2850#, which is the value of the maximum pressure, on the outer part of the cantilever.

We will consider a strip one foot wide. The total load, therefore, on the cantilever section will be 2850 x 9.5 = 27100#. The moment = 27,100 x 4.75 x 12 = 1,545,000"#.

The rods are to be placed 4" from the bottom, d is 80". (The section under investigation is the one which is perpendicular to the top of the base and passes along the edge of the square part of the base at the top. It is 8' from the center of the base. The maximum moment occurs at this section). $b = 12"$ $f_s = 16{,}000$ $j = .87$ and $f_c = 650\#$ per square inch.

$$p = \frac{M}{f_s \; j \; bd^2}$$

$$p = \frac{1{,}545{,}000}{16000 \times .87 \times 12 \times 80^2} = .0015$$

$p = \frac{A}{bd}$, $A = pbd = .0015 \times 12 \times 80 = 1.38$ square inches.

INVESTIGATION FOR PUNCHING SHEAR.

Circumference of chimney at the bottom equals 562".
The weight of the chimney equals 734,000#
Since the section is 7' deep or 84", the punching shear will be $= \frac{734,000}{562 \times 84} = 15.5\#$. As this value is well within the allowable stress for punching shear, there will be no danger of the chimney failing by shear.

The rods are placed as shown on the drawing. They are placed in such a manner so that there is the maximum number of rods at the sections of greatest bending moment,and a minimum amount at the outermost sections where the bending moment is the least. The arrangement of the rods affords a better distribution of the stresses when the wind is blowing in a direction diagonal to the base.

ESTIMATE OF COST.

The cost of material and labor given in this estimate was obtained from the Heine Chimney Co. and represents the prices paid for material and labor by this Company previous to May 1st, 1921.

ESTIMATE OF MATERIAL USED

The concrete will be 1:2:4: mix throughout. The volume of concrete in place is 10900 cubic feet or 404 cubic yards.

For 1:2:4 concrete.

The cement required = 1.48 barrels per cubic yard.

The sand required = .45 cubic yards per cubic yard.

The stone required = .90 cubic yards per cubic yard.

Total number of barrels of cement required = 404 x 1.48 = 598 barrels.

Total number of cubic yards of sand required = 404 x .45 = 182 cubic yards.

Total number of cubic yards of stone required = 404 x .90 = 364 cubic yards.

Amount of steel required.

Vertical steel.

From the top of the chimney to section approximately 75' from the top. Use 22, ½" square rods.

The weight = .85 x 22 x 89 = 1660#

From section approximately 75' from the top to section approximately 125' from the top. Used 22, 5/8" square rods.

The weight = 1.328 x 22 x 55½ = 1620#

From section approximately 125' from the top to section approximately 175' from the top. Used 30, 5/8" square rods.

The weight = 1.328 x 30 x 55½ = 2200#

From section approximately 175' from the top to the base of the chimney. Used 27, 3/4" square rods.

Weight = 27 x 34 x 1.913 = 1760#

HORIZONTAL REINFORCEMENT

The number required is 260. Used ½" round rods. Average length approximately 36'.

Weight = 36 x 260 x .668 = 6250#

FOUNDATION STEEL

Used 7/8" round rods. Number of longitudinal and transverse rods is 68.

Weight = 68 x 34 x 2.044 = 4750#

For diagonal rods the number required is 54. Used 7/8" round rods.

Weight = 35 x 54 x 2.044 = 3880#

TOTAL WEIGHT OF STEEL

	1660
	1620
	2200
	1760
	6250
	4750
	3880
Total	22120

COST OF MATERIAL

Cement	598 bbls.	@	$2.50	$1495.00
Sand	182 cu.yds.	@	1.75	318.50
Stone	364 " "	@	1.75	637.00
Steel	22120#	@	3.85 M	826.00
Wire mesh	800 sq.ft.	@	2.90 M	23.20
Brick	15 M	@	18.00 M	270.00
Mortar	9 yds.	@	7.00	63.00
	Total cost of material -			$3632.70

LABOR

FOR SHAFT

Cleaning down			$58.00
1 foreman	35 days @	$6.50	227.00
1 assistant	35 days @	5.50	193.00
4 men - each 35 days	140 days @	5.00	700.00
Concrete mixer	35 days @	1.00	35.00
Hoist	35 days @	1.00	35.00
			Tot. $1248.00

FOUNDATION

Excavating	299 yds.	@	$1.00	$299.00
Concrete - mixing & hauling	299 "	@	1.50	448.50
			Tot.	$747.50

LINING

Labor	$200.00

MISCELLANEOUS

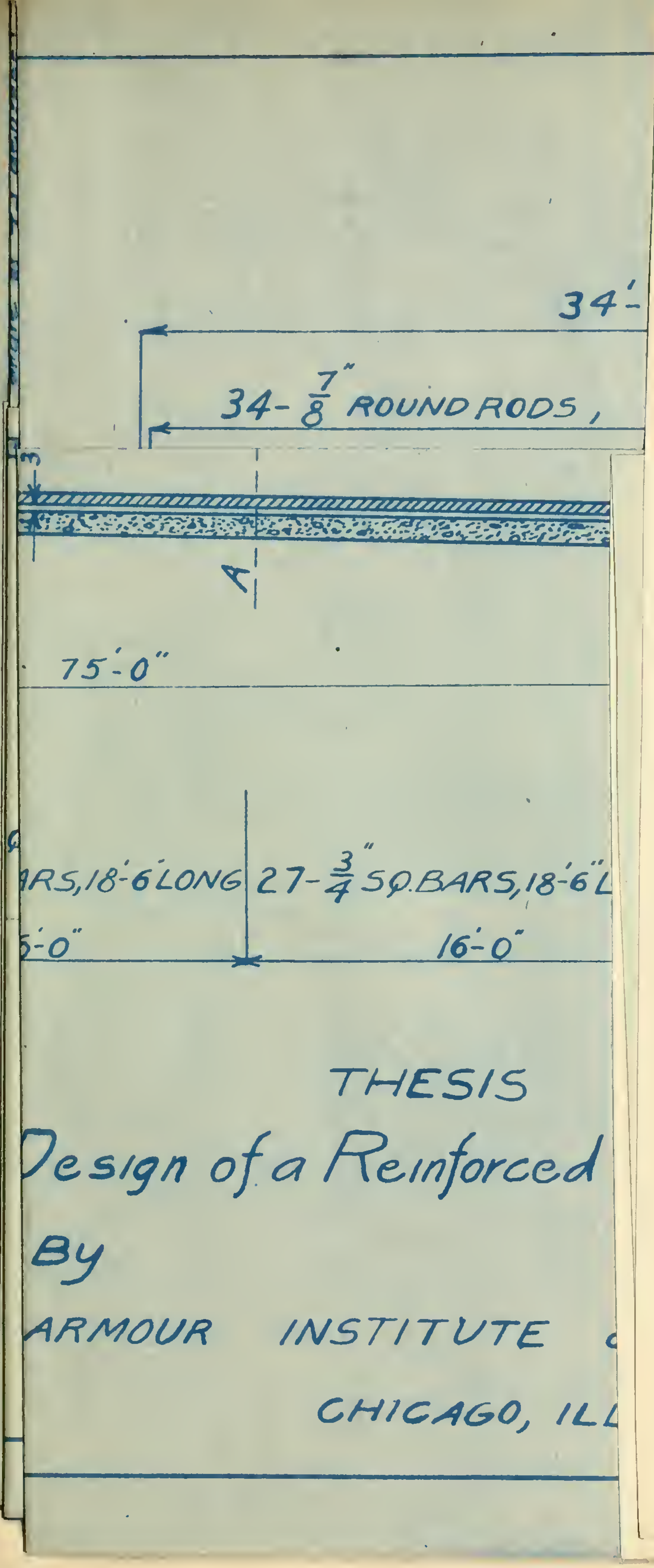
Pulley	35.00
Clean out door	20.00
Head forms	20.00
Forms	180.00
Scaffold	200.00
Tools, etc.,	25.00
Lumber for general use	40.00
General labor	25.00
Probable insurance	200.00
	$745.00

Total cost of material	$3632.70
Total cost of labor	1995.50
Total cost of lining	200.00
Total cost of miscellaneous	745.00
GRAND TOTAL	$6573.20

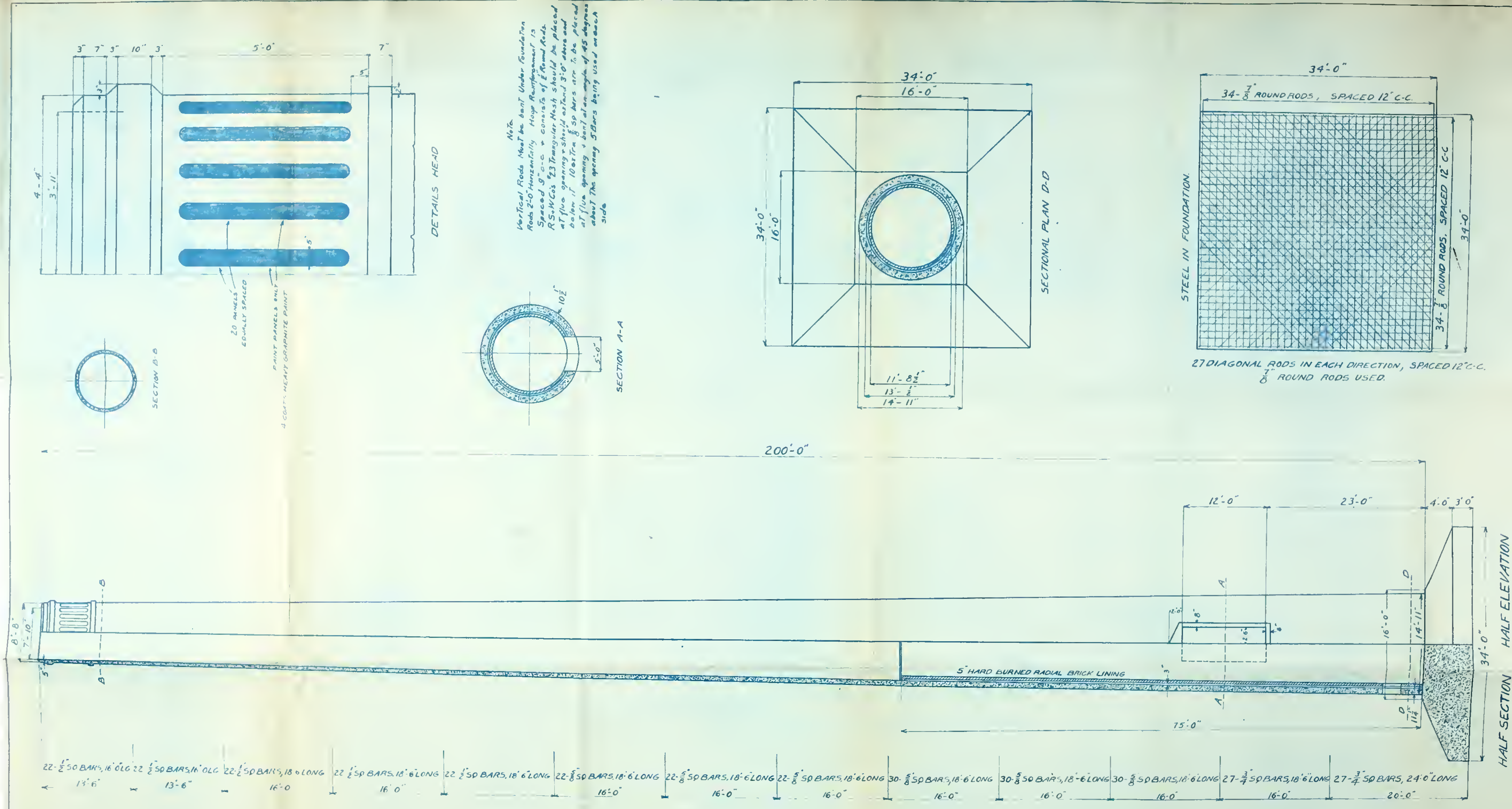
THE LINING

The lining will consist of 5" hard burned radial brick, which will be placed from the base to a distance of 75' from the base, and the outer edges of the brick must be spaced three inches from the inner edge of the concrete shell.

The lining is used as a means of protecting the concrete from the excessive heat of the gases, that are just entering the chimney. It is a known fact that the gases cool considerably as they ascend in the chimney. Hence there is little necessity of using the brick lining at a greater height than 75 feet from the base.



34'-
34- 7/8" ROUND RODS,
3
A
75'-0"
ARS, 18'-6 LONG
27- 3/4" SQ. BARS, 18'-6" L
5'-0"
16'-0"
THESIS
Design of a Reinforced
By
ARMOUR INSTITUTE
CHICAGO, ILL



THESIS

The Design of a Reinforced Concrete Chimney

By S. J. Burke

19-ARMOUR INSTITUTE of TECHNOLOGY-21.

CHICAGO, ILL.